COMMENTARY

Ancient agriculture and climate change on the north coast of Peru

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Because of its long-term perspective on human–environment relationships, archaeology is well positioned to study how people respond to past climate change and natural disasters. In interpreting these relationships, archaeological perspectives have shifted from viewing people as passively reacting to environmental change, to instead focusing on human action, decision making, and resilience theory (1). Adopted from ecology, resilience theory emphasizes how people foresee, adapt, and recover from disasters without significant cultural disruptions (2). As a theoretical tool, the concept of resilience enables archaeologists to consider the social and economic mechanisms that allow people to withstand periods of climate flux. One way of studying resilience to climate shifts is through the study of farming systems (3). In a paper titled "El Niño resilience farming on the north coast of Peru" in PNAS, Caramanica et al. (4) present evidence that the ancient inhabitants of the Chicama Valley developed sophisticated, flexible systems of agriculture to manage "catastrophic" El Niño (El Niño–Southern Oscillation [ENSO]) flooding over the last 2,000 y. These findings prompt reconsideration of the malleability of ancient Peruvian agricultural systems and how archaeologists think about disaster.

Ancient Irrigation in Coastal Peru

At first glance, coastal Peru appears to be a difficult environment for human settlement. The region is a hyperarid desert that is susceptible to water shortages, tectonic activity, and episodic, but devastating flooding brought on by ENSO (5). However, the area also has environmental advantages that served as the economic basis for complex societies for millennia (6). The Pacific coast is home to one of the world's richest marine ecosystems, which supported large fishing communities throughout prehistory (7, 8). In addition, the desert coastline is watered by a series of river systems fed from the adjacent Andes mountains, enabling irrigation agriculture. On the north coast of Peru, irrigation developed over thousands of years (9) evolving into a sophisticated, spatially extensive system that reached its greatest extent in the Late Intermediate Period (LIP) (ca. AD 1000–1480) (5, 10–13) and boasted some of the largest irrigation infrastructure in the ancient Americas (14). These irrigation systems formed the economic basis for the large-scale urban polities of the Moche (AD 100–800) and Chimú civilizations (AD 900–1480) (10).

However, these irrigation systems were also vulnerable to periodic, unpredictable disruptions by the torrential rains associated with ENSO, which caused extensive flooding and debris flows that could block or damage canals and destroy agricultural fields (5, 15, 16). Paleoclimate studies suggest that modern periodicity of the ENSO phenomenon of 6 to 20 y was underway by ca. 3000/2900 BP (17, 18). Because of these hazards, archaeologists have long been interested in the cultural consequences ENSO had on ancient Peruvian civilization (17, 19, 20). However, for regions like the north coast, complex society thrived for thousands of years, implying that the different societies of the north coast were resilient to ENSO and thus raising the question of how these "disasters" were perceived and managed.

Agricultural and Resilience in the Pampa de Mocan

Caramanica et al. (4) studied long-term resilience through a diachronic study of agriculture in the Pampa de Mocan situated in the Chicama valley. Chicama has a complex anthropogenic landscape that developed over millennia (11, 21, 22). Today, the Pampa de Mocan is a barren landscape, but Caramanica et al. (4) report abundant archaeological evidence that this region was intensively farmed in antiquity, supporting claims that indigenous peoples cultivated more land than is under cultivation today (5). Through a sophisticated, interdisciplinary study drawing on archaeological survey, geoarchaeology, archaeobotany, and ethnography, Caramanica et al. provide a

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vivid empirical description of the ways people in this landscape managed and mitigated the threats of ENSO floods over a period of ca. 2,000 y.

The recovery of moisture-sensitive botanical remains from a well dating to the LIP served as a proxy for the environmental dynamism on the Pampa de Mocan over a period of approximately a century. While this sequence shows sedimentological evidence for periodic ENSO flooding, cultigens like maize were also present throughout the sequence, demonstrating continuity in agricultural practices despite recurrent disruptions. Furthermore, the authors convincingly demonstrate that El Niño precipitation produced a green, oasis-like landscape, similar in plant composition to vegetation blooms documented in the 2017 ENSO. Using this sequence as a model for the environmental prehistory of the Pampa de Mocan, Caramanica et al. point to some of the benefits that increased precipitation and flooding would have brought to the ancient farming populations.

A major outcome of the study was the detailed documentation and description of other types of agricultural fields that were used when irrigation canals failed or were significantly disrupted by flooding. These alternative systems included embankment fields, border-strip fields, and rockpile fields, each of which was designed to redirect floodwater and organic materials to agricultural fields, sometimes with features to reduce erosion and retain moisture. In some cases, these systems also repurposed previously abandoned canals. Caramanica et al. argue that floodwater structures, which constitute 28% of fields in the valley, were implemented as part of the perennial agricultural system. The documentation and description of floodwater technology adds to a growing corpus of data that coastal people developed agricultural infrastructure designed to cope with ENSO-induced flooding, including raised fields (23), check dams, and reservoirs (24).

Caramanica et al. make important methodological and theoretical contributions to the study of agricultural resilience. As the authors note (4), the presence of floodwater systems indicates that the inhabitants of the north coast incorporated ENSO into the normal ecological cycle. While it is currently unknown how productive floodwater systems were in comparison to large-scale irrigation, the pervasiveness of the former implies it was successful, at least in the short term. The design of the floodwater systems indicates sophisticated ecological knowledge that was developed through long-term experience with ENSO flooding. These findings complement research in the highland Andes where planning for periodic droughts in the Lake Titicaca Basin were built into flexible farming systems (25).

One direction for future research centers on determining how the north coast agriculture systems were organized and implemented on a sociopolitical level. The early writings of Karl Wittfogel (26) and Julian Steward (27) considered irrigation to be

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managed by centralized state-organized polities. In the case of the Peruvian coast example, some of the massive canals may have been top-down projects organized by the Chimú state government. However, the floodwater systems suggest more decentralized, "bottom-up" (28–30) labor projects that were locally organized by the communities living in the Pampa de Mocan. Historical study of Colonial period documents suggest elements of indigenous water management were organized by small-scale groups referred to as *parcialidades* (31), and this type of model may apply to the archaeological record. The observation by Caramanica et al. (4) that local communities in the region used similar floodwater techniques during the 2017 ENSO point to possible ethnographic analogies that merit further study. If floodwater (and canal) systems were organized in this manner, it would suggest that the burden of resilience (32) may have rested in commoner social groups, as opposed to elite segments of society.

Contemporary Implications for Disaster Response

Implications for Disaster Response There is a growing trend to leverage archaeological knowledge about human ecodynamics toward helping resolve the contemporary environmental problems of the Anthropocene (33). This is particularly relevant to Peru where ENSO frequency and strength are anticipated to increase because of global warming (34). Reports of the 2017 ENSO describe the displacement of just under 1.4 million people and billions of dollars in damage in north coastal Peru (35). Caramanica et al. argue that the contrasts between the ancient, flexible agricultural systems of the north coast are rooted in philosophical differences in what constitutes a disaster. While the modern Peruvian nation state views ENSO as an external natural disaster, Indigenous peoples of coastal Peru regarded ENSO as part of the socioecological norm. These different perceptions constrain the nature of response: flexibility or rigidity. Caramanica et al. raise the possibility that ancient systems could be implemented or reintroduced as an alternative, and in this sense move their research toward an archaeology of sustainability (3).

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